Technical Documentation to Support Development of Minimum Flows and Levels for the Caloosahatchee River and Estuary

Appendix G

The Significance of Tidal Runoff on Flows to the Caloosahatchee Estuary

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Summary:

This paper provides the first hydrologic summary of the entire Caloosahatchee Watershed. Until recently, there was neither measured nor modeled data for the tidal portion of the watershed. Recently, however, a coupled surface water – groundwater model was developed by DHI for the Tidal Caloosahatchee. In this paper, an empirical model of the Tidal Caloosahatchee is calibrated to the DHI model and used to estimate tidal inflows for the extended time-periods needed for ecological analyses. The estimates of tidal runoff are combined with upstream flows (estimated by CERP models) to assess the distribution of total inflows to the Caloosahatchee estuary.

The Tidal Caloosahatchee makes up 30% (268,000 acres) of the watershed area (903,000 acres) and generates 28% (340,000 acre-feet per year) of the total watershed runoff 1,234,000 acre-feet per year). Historically, regulatory releases from Lake Okeechobee add an additional 24% (297,000 acre-feet per year) – mostly at damaging high rates of inflow.

CERP restoration will eliminate most regulatory releases and a substantial amount of non-beneficial basin runoff will be captured and redirected to beneficial uses: some to agricultural demands and some to restoring a natural estuarine flow pattern. The flow distribution for total watershed hydrology is developed for three situations: historic data, the CERP '1995 Base' scenario, and the CERP '2020 with Restudy Components' scenario. The '2020 with Restudy' scenario shows a more natural flow distribution than today's watershed.

Past work on estuary restoration, including current MFL flow targets, have been based on conditions in the upstream watershed (S-79 flows). Recent hydrodynamic salinity modeling shows that total freshwater inflows to the estuary of 500 cfs is more likely to keep salinities below 10 ppt throughout the Vallisneria seagrass beds. In a comparison of S-79 flows against total freshwater inflows it was found that, under current conditions (1995 Base), the 300 cfs flow criterion at S-79 provides and acceptable estimate of 500 cfs total inflows; correlating to total flows below 500 cfs 43% of the time and to total flows above 500 cfs 57% of the time. The

criteria of 300 cfs at S-79 flow will become less acceptable as Restudy components are constructed. Under the 2020 with Restudy scenario 300 cfs flows at S-79 correlate to total flows above 500 cfs only 19% of the time.

Introduction:

As part of the Southwest Florida Feasibility Study, DHI Water & Environment was contracted to develop a hydrologic model of the Tidal Caloosahatchee Watershed. This model, an application of the MikeShe code, has been completed (Petersen et al, in review). Completion of this model makes it possible, for the first time, to estimate inflows for the entire Caloosahatchee watershed. Section 1 presents a brief summary of the Tidal Caloosahatchee model.

The ecology of the estuary is known to depend on freshwater inflows and many problems in the estuary have been attributed to poor management of these freshwater inflows. The C&SF Comprehensive Restudy has proposed the construction of several water management facilities to restore freshwater flows to the estuary.

The objective of this paper is to assess freshwater inflows over a wide variety of climate conditions using a long (thirty-one year) simulation. Unfortunately, results from Tidal Caloosahatchee Watershed were only available for three years. Therefore, an application model, calibrated to the MikeShe model, was created. The application model is based on linear reservoir theory. Section 2 paper describes the linear reservoir model and compares it to the MikeShe model. Section 3 applies the model to the entire thirty-one year period of simulation.

In section 4, thirty-one year time-series of Caloosahatchee Estuary inflows are created by combining Tidal Caloosahatchee runoff with flows from the rest of the watershed (S-79 flows). Three different sets of estuary flows are created and compared: measured data, the C&SF '1995 Base' scenario, and the 'C&SF 2020 with Restudy Components' scenario. Measured data show historic conditions; '1995 Base' shows conditions as they exist today in the watershed; '2020 with Restudy Components' shows conditions in 2020 after the proposed water management facilities are constructed.

Section 5 uses the '1995 Base' and '2020 with Restudy Components' hydrology to examine the suitability of the current MFL flow criterion of 300 cfs at S-79.

Summary of the MikeShe Tidal Caloosahatchee Basin Model

The Tidal Caloosahatchee Basin Model (Petersen et al, in review) is an application of the MikeShe code. The model is a fully coupled surface water and groundwater model intended to accurately simulate all significant hydrologic process in the watershed including evaporation, runoff, stormwater detention, river hydraulics, stream water management, groundwater withdrawals and recharge, etc.

The area modeled is shown in **Figure G-1**. **Table G-1** shows the areas of the drainage basins within the study area that drain into the Caloosahatchee. The Tidal Caloosahatchee watershed is 268,000 acres (30%), compared to the portion of the non-tidal portion of the Caloosahatchee, which is 634,000 acres.

The consultant was requested to make a special simulation examining the spatial distribution of inflows into the estuary and describing inflow sources (Petersen and Copp, 2002). The MikeShe runoff time-series is shown on **Figure G-2**. Although measured stream flow data in the basin are sparse, DHI calibrated to all available data: flows, groundwater elevation data and stream stage data. For the purposes of this paper, the MikeShe flow data are assumed to be accurate.

The spatial distribution of flows entering the estuary are shown in **Figure G-3** and tabulated in **Table G-2**. The largest single inflow (30% of the total) comes from Orange River (river segment 3: six miles downstream of S-79). Substantial volumes (17%) enter far downstream (segment 10: twenty-six miles downstream of S-79). This spatial distribution was relatively constant over the simulation period.

The Linear Reservoir Model for the Tidal Caloosahatchee Basin

A linear reservoir (LinRes) model was developed for the Tidal basin because MikeShe results were only available for a three-year simulation period while flows are needed for a thirty-one year period of simulation. The Linear Reservoir Model was developed because it is fast, reliable, and easily calibrated against the MikeShe model.

The model has three cascading reservoirs and a root zone. Rainfall and evaporation fill and empty the root zone with excess root zone water recharging the storage zones (linear reservoirs). The storage zones drain at a rate exponential to storage. There is also a term for rain falling directly on the streams and estuary. The equations are:

Root Zone:
potential change = max(0, Rain – PET + root zone storage)
root zone storage = min(max(0,(potential change)),root zone capacity)
actual ET = PET - max(0,-(potential change))
water to add to zone 1= max(0, potential change - root storage capacity)

For Each Zone:
addwater : excess water defined in previous zone
storage = min(max(0,(addwater + storage –outflow)),maximum capacity)
ouflow = (storage) *(1-exp(-1/ storage coefficient))
addwater for next zone = max(0,(addwater + storage –outflow)) - maximum capacity

[Fluxes are measured in inches per day and are converted to acre-feet per day by multiplying by the watershed area.]

The LinRes model was calibrated to MikeShe results, using the same rainfall and PET data. Since MikeShe simulates three flow types: aquifer flow (AQ), shallow drainage flow (DR) and overland flow (OVL), the conceptual reservoirs of LinRes were calibrated to match each MikeShe flow type. Time-series for each flow type (not shown here) were developed; the average annual flow for each type is shown on **Table G-4**. [Note: Reservoir 1 simulates AQ flow, Reservoirs 2 and 3 simulate DR flow, OVL flow is simulated best using the direct rainfall.] **Table G-3** shows the calibrated model parameters.

The final model matched the MikeShe model well and had a Pearson correlation coefficient of 0.878. Figure 2 shows the time-series for both the MikeShe and the LinRes model over the three-year simulation.

Tidal Hydrology over a Thirty-Six Year Period of Simulation

The calibrated LinRes model was used to generate a thirty-six year (1965-2000) time-series of tidal watershed runoff. Rainfall and PET data came from Ft Myers (prepared for regional modeling efforts). A general summary of the hydrology is shown in **Table G-4**. Note the variability of rainfall and runoff. The three-year calibration period averaged 65.1 inches per year of rain and 26.1 inches per year of runoff (584,000 acre-foot per year) while the thirty-six simulation period had only 56.2 inches per year of rainfall and 16.2 inches per year of runoff (362,000 acre-feet per year). Slow draining aquifer flow (AQ) makes up 23% (84,000 acre-feet per year) of the total. Aquifer drainage is about the same magnitude as the rainfall that falls directly onto the open-water of estuary (90,000 acre-foot per year).

Figure 4 shows daily tidal basin runoff for the thirty-one year simulation period (1965-1995). This simulation period matches the CERP simulation period. Local basin runoff averages 340,000 acre-foot per year and peak daily runoff rates regularly exceed 5000 cfs.

Comparing Estuary Hydrology for Three Scenarios

Salinities in the Caloosahatchee Estuary depend on total estuary inflow. Flows from the tidal basin (above) are combined with flows from the rest of the watershed to generate time-series of total estuary inflows. The Caloosahatchee Estuary receives distributed flows from the Tidal Watershed and a very large point source at the S-79 structure (aka Franklin Lock and Dam) at the downstream end of the C-43 canal. Flows at S-79 are generated within the upstream watershed: i.e. the East Caloosahatchee Basin, the West Caloosahatchee Basin, and the S-4 Basin; S-79 flows also include occasional but substantial (and damaging) regulatory releases from Lake Okeechobee that pass through the C-43 canal into the estuary.

Three time-series for S-79 flows are combined with tidal basin flows and examined: measured S-79 data, 1995 Base, and 2020 with Restudy Components. ‘Measured’ data represent the historic watershed; ‘1995 Base’ data represents the current conditions; ‘2020 with Restudy Components’ represents the proposed CERP solution. [One of the CERP objectives is to restore conditions within the Caloosahatchee Estuary via reservoirs, STAs, etc. The ‘2020 with Restudy Components’ models the ‘yellow book’ components. (These components are being refined as part of the C-43 PIR process. No refined hydrology is yet available.)]

Figure G-5 shows the time-series for total freshwater inflows to the estuary for the ‘1995 Base’ and ‘2020 with Restudy Components’ scenarios. Notice the variability in both time-series; several years in a row without large runoffs and also several years with many large runoffs in the same year. This variability is rain-driven and natural. Also notice the difference between the two time-series. The '2020 with Restudy Components' has raised the baseflow components and reduced peak flows.

Figure G-6 shows the probability flow-distribution of freshwater inflows for '1995Base' and '2020 with Restudy Components' scenarios. The same data is shown in tabular form in **Table G-6.** The frequency analysis shows that today's estuary is frequently exposed to low flows. [These result in high salinities that stress the Vallisneria sea-grasses. Recent hydrodynamic-salinity modeling has found that total freshwater inflows of 500 cfs are needed to keep salinities below 10 ppt throughout the productive Vallisneria sea-grass beds. (Qiu, personal communications).]

Under 1995 Base 41% of the months have flows below the 500 cfs threshold needed to protect the seagrass beds. Severe stress is also common with 32% of all months having flows below 325 cfs. Flows are much better for the '2020 with Restudy Components' scenario. Only 18% of the months have flows below the 500 cfs threshold and severe stress is almost eliminated with only 2% of months having flows below 325 cfs.

Total Caloosahatchee Flows under Current MFL Criteria

Existing minimum flow criteria are 300 cfs at S-79. These criteria were established without quantitative consideration of inflows from the unmonitored tributaries and groundwater inflows of the tidal basin. Now that hydrology is available for the entire watershed, this minimum flow value can be reassessed.

Hydrodynamic modeling shows that a combined flow of 500 cfs is necessary to keep salinities below 10 ppt throughout the critical seagrass beds. The combined watershed hydrology can be examined under current MFL conditions (300 cfs) to determine how well the MFL flow correlates to the target watershed flow of 500 cfs.

Table 7 looks at monthly watershed inflows, for all scenarios, when monthly S-79 flows are near 300 cfs (275 to 325 cfs). The frequency analysis of 1995 Base shows that 300 cfs at S-79 correlates reasonably well to the 500 cfs total flow target. When S-79 flows are near 300 cfs, total flows are between 325 cfs and 500 cfs about half of the time (43%) and between 500 cfs and 800 cfs about half of the time (43%).

The correlation of S-79 flows of 300 cfs and total flows of 500 cfs breaks down under the '2020 with Restudy Components' scenario. Under this scenario, when S-79 flows are near 300 cfs, total flows are below 500 cfs most of the time (80%) and between 500 cfs and 800 cfs only 20% of the time.

It is not surprising that the correlation of S-79 flows and total flows changes in the 2020 scenario; reservoirs and ASRs upstream of S-79 are designed to deliver base flows to the estuary. This shifting of sources is demonstrated in Figure 7. Figure 7 shows the contribution of upper basin flow as a percentage of total estuary inflow for both 1995 base and 2020 with Restudy scenarios. Under 1995 Base, upper basins contribute 42% of flows in the 325 cfs - 500 cfs range and 62% of flows in the 500 cfs – 800 cfs range. Under 2020 with Restudy, upper basins contribute 78% of flows in the 325 cfs - 500 cfs range and 70% of flows in the 500 cfs – 800 cfs range.

In summary, it would be better to base protection criteria on total estuary inflows (500 cfs) than on S-79 flows (300 cfs). Under current conditions (1995 Base), the 300 cfs flow criterion at S-79 is an acceptable surrogate for total estuary inflows of 500 cfs; correlating to total flows below 500 cfs 43% of the time and to total flows above 500 cfs 57% of the time. The criteria of 300 cfs at S-79 flow will become less acceptable as Restudy components are constructed. Under the 2020 with Restudy scenario 300 cfs flows at S-79 correlate to total flows above 500 cfs only 19% of the time.

References:

Tidal Caloosahatchee Basin Model - Model Calibration and Validation, Michael J. Petersen, Joseph D. Hughes, Jeremy McBryan, Roger Copp and Torsten V. Jacobsen, DHI Water & Environment, Project 51189, July 2002

Summary Descriptions of Groundwater and Tributary Flows to the Caloosahatchee River. Michael J. Petersen, and Roger Copp, DHI Water & Environment, Project 51189, August 22 2002

Table G-1. SFWMD Drainage Basins in Caloosahatchee Watershed

	Acres	Mi^2
Basins draining directly into Tidal Caloosahatchee Estuary		
Tidal Caloosahatchee Basin	196,140	306
Telegraph Basin	56,474	88
Caloosahatchee Estuary	15,376	24
SUB-TOTAL	267,990	418
Basins draining into Estuary at S-79		
East Caloosahatchee Basin	226,631	354
West Caloosahatchee Basin	356,928	558
S4 Drainage Basin	50,269	79
SUB-TOTAL	633,828	990
TOTAL	901,818	1409

Table 2. Spatial Distribution of Tidal Caloosahatchee Inflows (MikeShe estimates)

River Segment	Station (Miles Downstream of S-79)	Fraction of Flow Entering at each Station
1	0.44	9%
2	5.09	7%
3	7.13	29%
4	8.16	3%
5	9.09	8%
6	11.69	5%
7	15.11	7%
8	18.66	7%
9	21.84	8%
10	25.93	17%

Table 3. Parameters of Linear Reservoir Model of Tidal Caloosahatchee Basin

Area of Basin	267,990 acres		
Rainfall	1965-2000 measured data (Thiessen polygon average of 10 stations)		
Evapotranspiration	1965-2000 pseudo-Penman data for Fort Meyers		
Root Zone	6.85 inches		
Direct Flow	100% of rainfall over 19,207 acres		
Linear Reservoirs		Maximum Storage (in)	Storage Coeff (in/d)
	Rapid Flow	5	8
	Moderate Flow	1	100
	Slow Flow	2.6	110
Pearson GOF v MikeShe Results	R = 0.878		

Table 4. Comparing Tidal Caloosahatchee Models

Model	**p.o.s.**	**Rainfall (inches per year)**	**Runoff (inches per year)**	**Runoff (acre-foot per year)**			
				Total	**AQ**	**DR**	**OVL**
MikeShe	1998-2000	65.1	26.1	583,298	104,949	373,531	104,819
LinRes	1998-2000	65.1	26.1	584,092	119,630	360,421	104,042
LinRes	1965-2000	56.2	16.2	362,488	83,856	188,605	89,927

Table 5. Annual Flows into the Caloosahatchee Estuary: 1965-1995

	Measured	**1995 Base**	**2020 with Restudy**
	Average Annual Flow (af/year)		
Tidal Caloosahatchee Basins	339,471 (22%)	339,471 (24%)	339,471 (32%)
S-79 Flow	1,190,097 (78%)	1,070,637 (76%)	717,705 (68%)
E & W Caloos Basins	893,387 (58%)	703,322 (50%)	689,217 (65%)
Regulatory Releases	296,710 (19%)	367,314 (26%)	28,488 (3%)
TOTAL	1,529,568	1,410,108	1,057,176

note: 1995 Base is from Regional Modeling (95BSRR)
note: '2020 with Restudy Components' is from Regional Modeling (2020R1)

Table 6. Frequency Distribution of Total Estuary Inflows (see also Figure 5).

	Probability of Monthly Flows within Flow Range		
Flow Range	**measured**	**1995 Base**	**2020 with Restudy Components**
<325 cfs	23%	32%	2%
325 to 500 cfs	9%	9%	16%
500 to 800 cfs	12%	6%	32%
800 to 1500 cfs	13%	12%	25%
1500 to 2800 cfs	17%	13%	10%
2800 to 4500 cfs	11%	14%	9%
4500 to 8000 cfs	11%	9%	4%
>8000 cfs	4%	4%	1%

Table 7. Evaluating watershed inflows when S-79 monthly flows are near 300 cfs (275 to 325 cfs)

	probability total flow in range (cfs)		
Total Flow	**measured**	**95base**	**2020 with Restudy Components**
<325 cfs	7%	0%	13%
325 to 500 cfs	53%	43%	68%
500 to 800 cfs	33%	43%	20%
800 to 1500 cfs	7%	14%	0%
1500 to 2800 cfs	0%	0%	0%
2800 to 4500 cfs	0%	0%	0%
4500 to 8000 cfs	0%	0%	0%
>8000 cfs	0%	0%	0%
months is in range	15	14	40

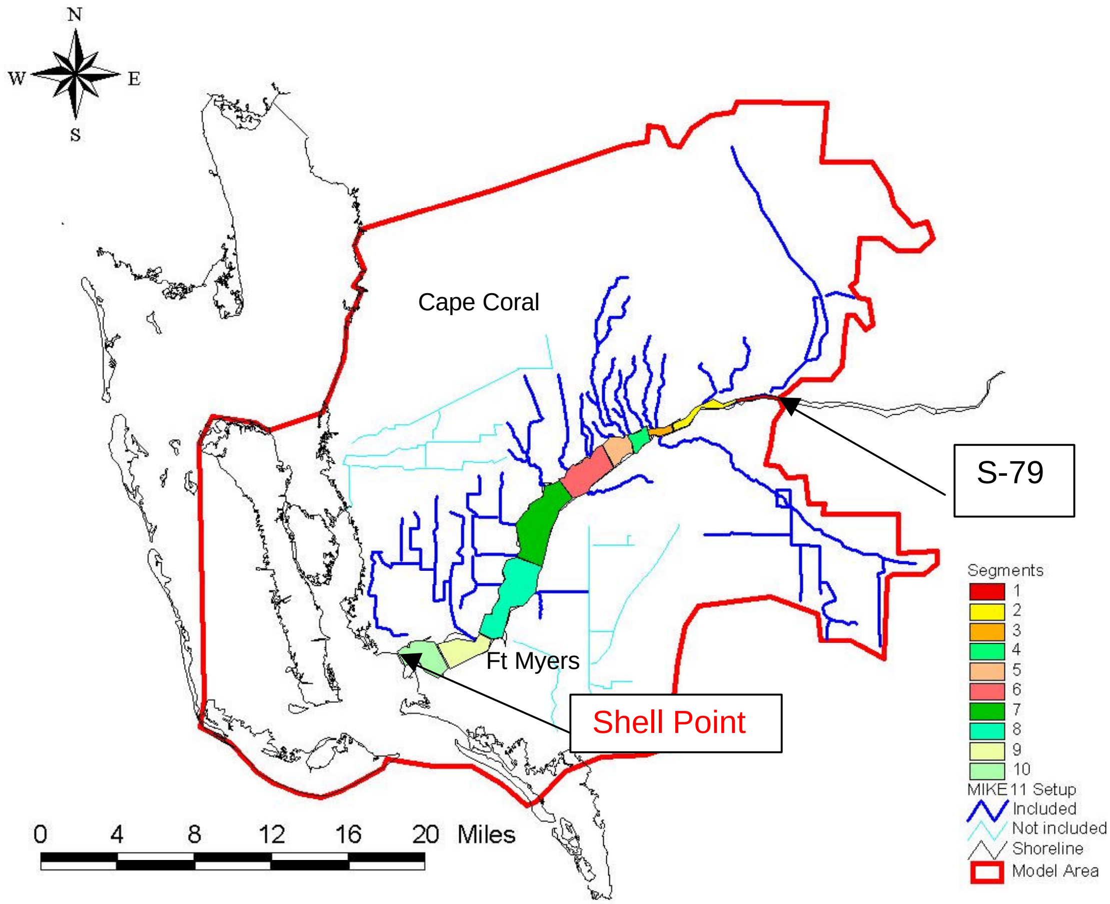

Figure G-1 – Segments of the Caloosahatchee River Estuary Receiving Inflows from the Tidal Caloosahatchee River Watershed

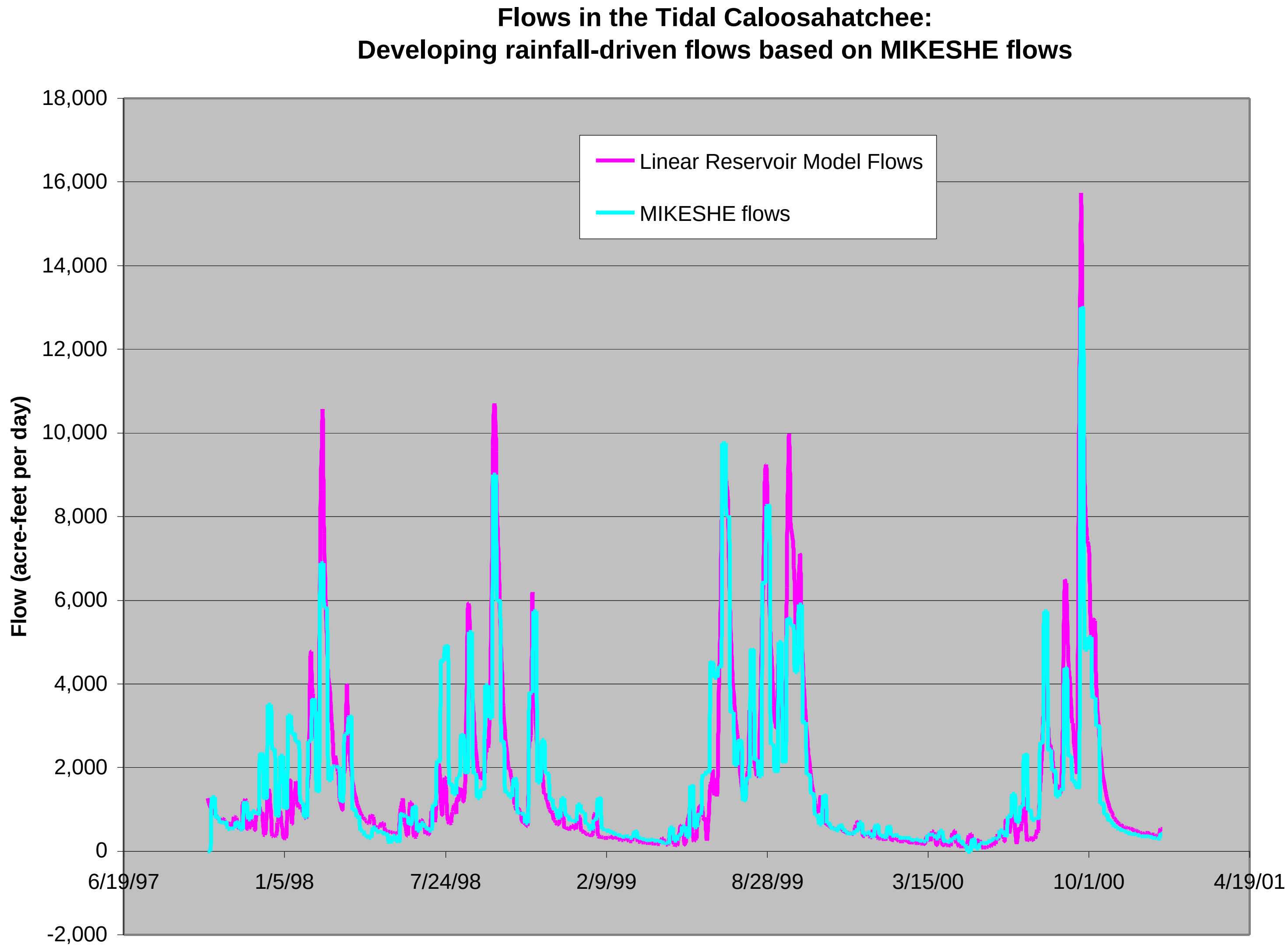

Figure G-2. Comparison of 5-day flows: MikeShe Model for the Tidal Caloosahatchee Basin and Calibrated Linear Reservoir Model.

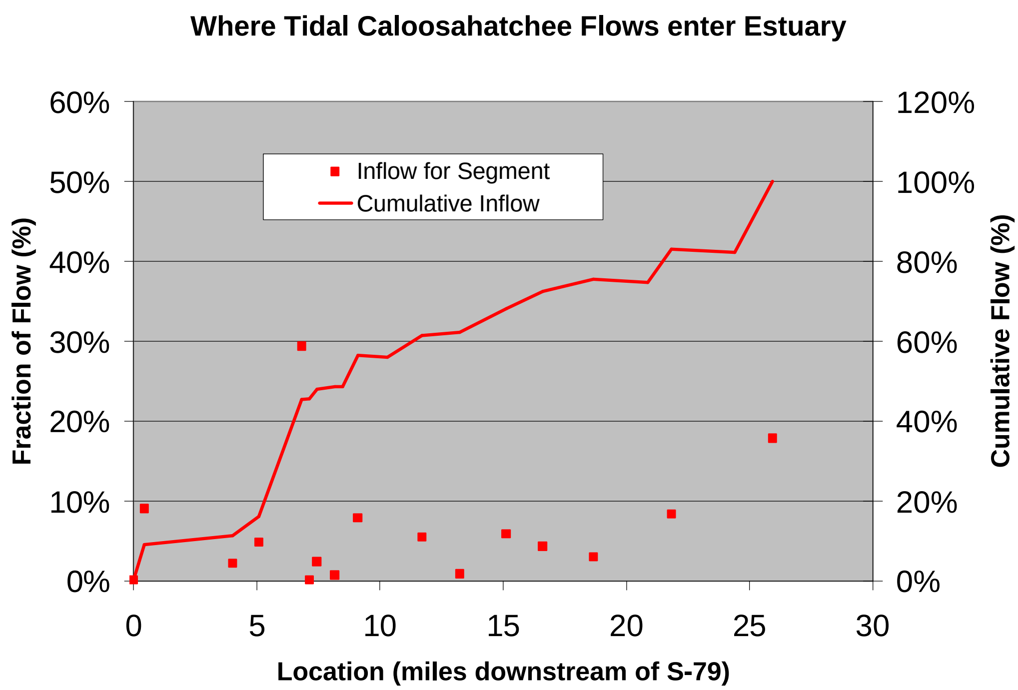

Figure G-3. Typical Spatial Distribution of Tidal Caloosahatchee Inflows

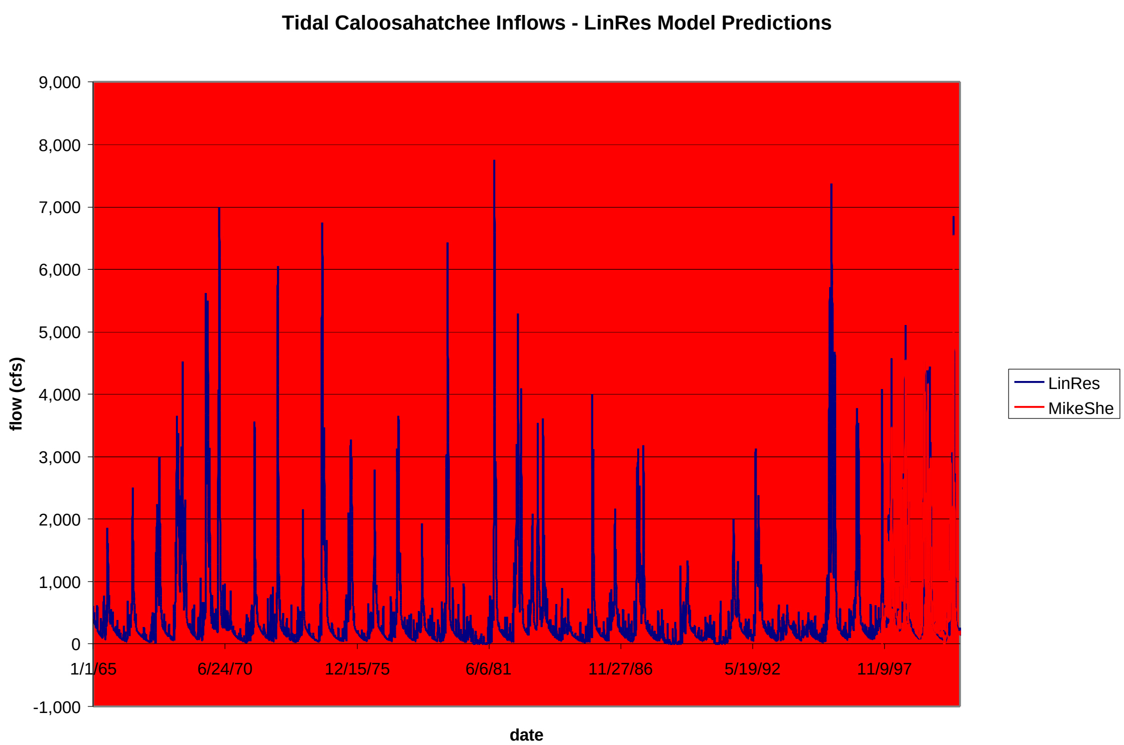

Figure G-4. Tidal Caloosahatchee Daily Flows predicted by LinRes model

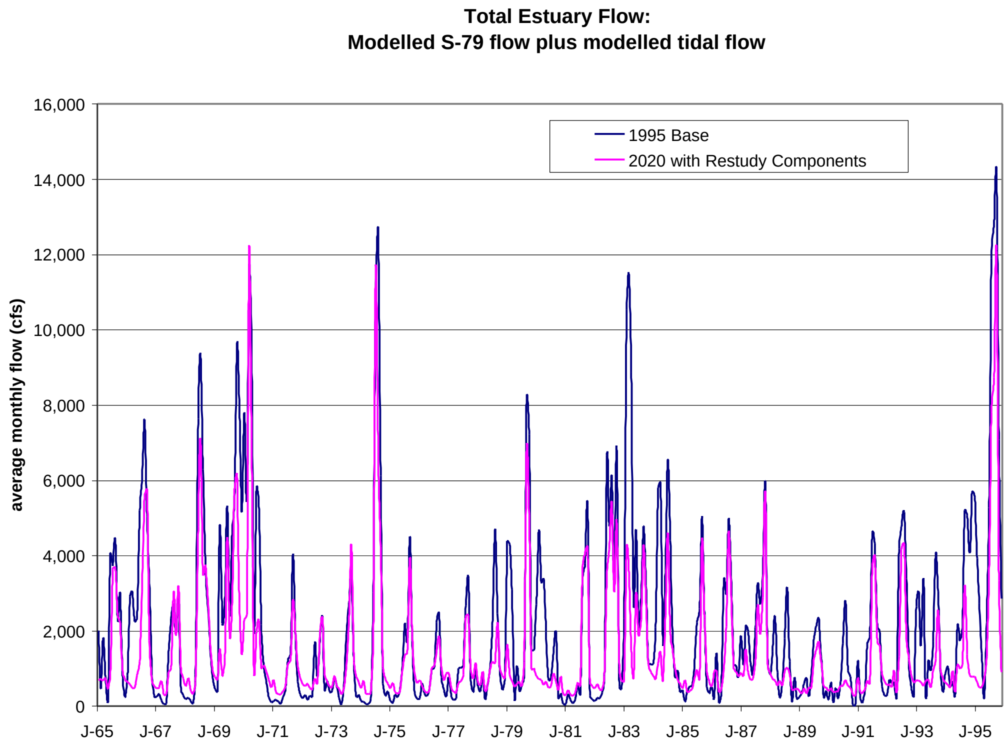

Figure G-5. Average Monthly Caloosahatchee Estuary Inflows: modelled S-79 flow for 1995 Base and 2020 with ReStudy - each combined with LinRes estimates of tidal flow.

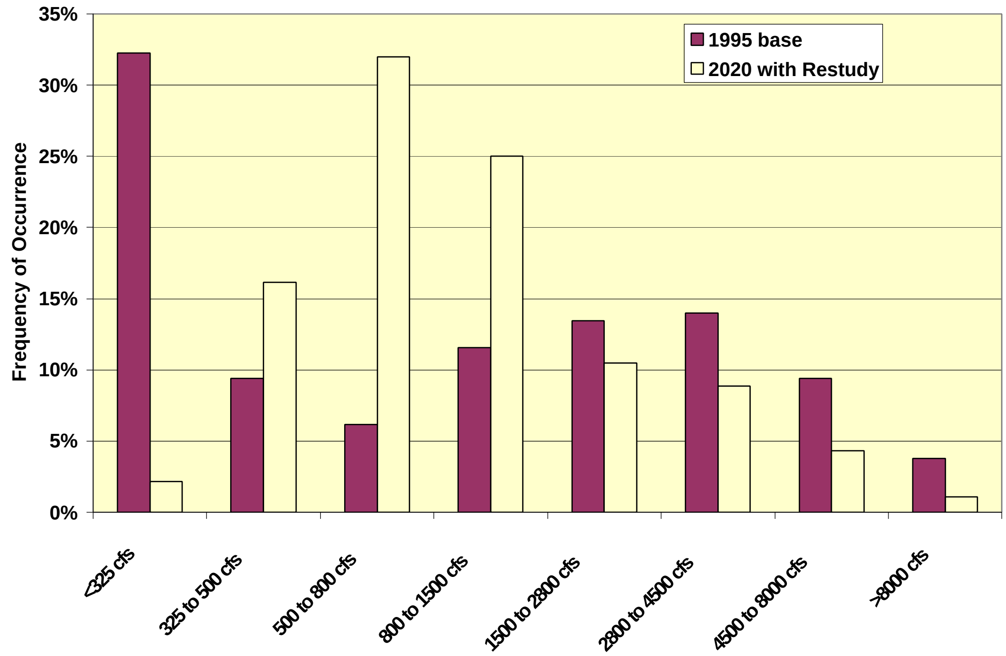

Figure G-6. Distribution of Average Monthly Caloosahatchee Estuary Inflows – 1965 to 1995. Inflows include Upper Basins, Tidal Basin, and Lake Okeechobee regulatory releases.

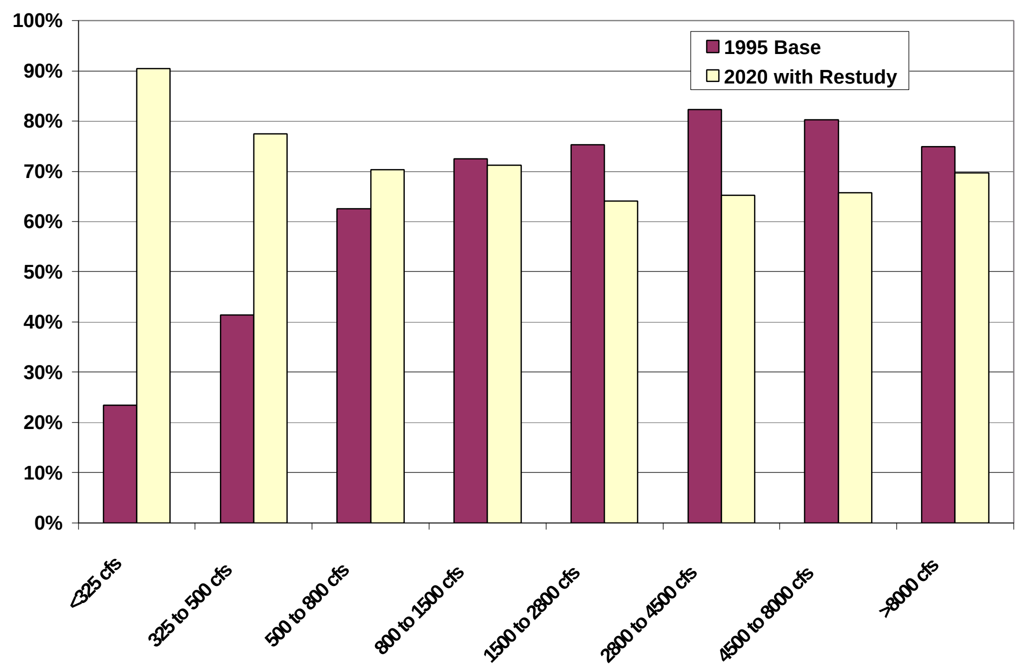

Figure G-7. Percentage of Average Monthly Caloosahatchee Estuary Inflows contributed by Upper Basins.